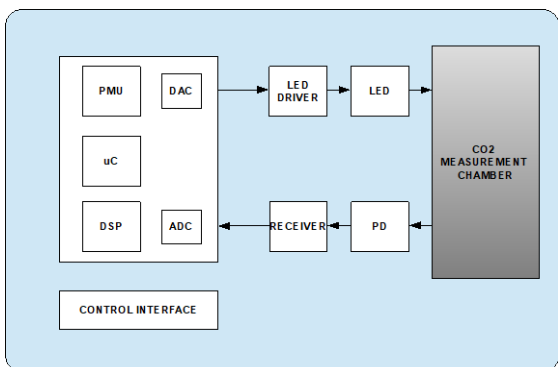


## ABSTRACT

All GSS sensors use a technique called non-dispersive infra-red (NDIR) sensing where light from a LED is injected into the optical measurement chamber, which contains the gas which has been allowed to enter it. The light that passes through the optical cavity is detected by the photo diode. The signal from the photo diode is digitised by the microcontroller and compared with a reference level stored in memory. The microcontroller can then calculate the level of CO<sub>2</sub> in the optical measurement chamber.



The performance of an NDIR sensor can be compromised by condensation that gets deposited on the surface of the optical cavity. This happens when the temperature of the optical surface is below the dew point. A typical example is when the sensor is moved from a cold place into a higher temperature and moist atmosphere.

The impact of the condensation on the optical surface causes the sensor to read erroneously high. The signal from the LED gets partially blocked or attenuated by the water vapour that has condensed on the surface, and this is translated by the sensor into a high gas

concentration. Whilst condensation will not directly damage the sensor, it can carry contaminants that will degrade the optical surfaces over time. Care should be taken to eliminate the conditions where condensation might occur and to ensure that if condensation does occur, inappropriate action is not taken due to the abnormally high readings from the sensor.

This application note describes the environmental operating range of GSS sensors, the effect of condensation on the sensor and potential mitigation strategies if there is a high likelihood of the sensor encountering condensation conditions.

**Learn more about our CO<sub>2</sub> Sensors here!**

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## CAUSES OF CONDENSATION

Condensation is caused due to water vapour in the air or gas depositing itself on solid surfaces that are at lower temperatures than the surrounding air. When moist air or gas containing water vapour comes into contact with a cold impermeable surface, it releases some of this moisture onto the surface as water droplets. This is condensation.

The dew point is the temperature at which the moist air or gas becomes saturated with water vapor, which is the gaseous state of water. When the gas containing the water vapour has reached the dew-point temperature at a particular pressure, the water vapor in the gas is in equilibrium with liquid water, meaning water vapor is condensing at the same rate at which liquid water is evaporating.

Therefore, below the dew point, liquid water will begin to condense on solid surfaces. The dew point is closely linked to relative humidity, which is the ratio of the pressure of water vapor in a parcel of air relative to the saturation pressure of water vapor in that same parcel of air at a specific temperature. Relative humidity (RH) is expressed as a percentage.

GSS sensors are calibrated to operate over two temperature ranges, either 0°C to +50°C or -25°C to +55°C and within environments where the non-condensing RH is less than 95%. Care must be taken to ensure the sensor surface temperatures are not below the dew point, otherwise water will begin to condense on the optical surfaces, compromising sensor accuracy and performance.

The dew point calculation method is complicated but can be approximated to the following formula for temperatures ranging from -45°C to 60°C.

$$\text{Dew Point Temperature (Tdp)} = \frac{(b * \alpha(T, RH))}{(a - \alpha(T, RH))}$$

Where;

- T = Ambient temperature
- RH = Relative humidity (%)
- a and b are coefficients where a = 17.62 and b = 243.12°C
- $\alpha(T, RH) = \ln(RH/100) + a*T/(b+T)$

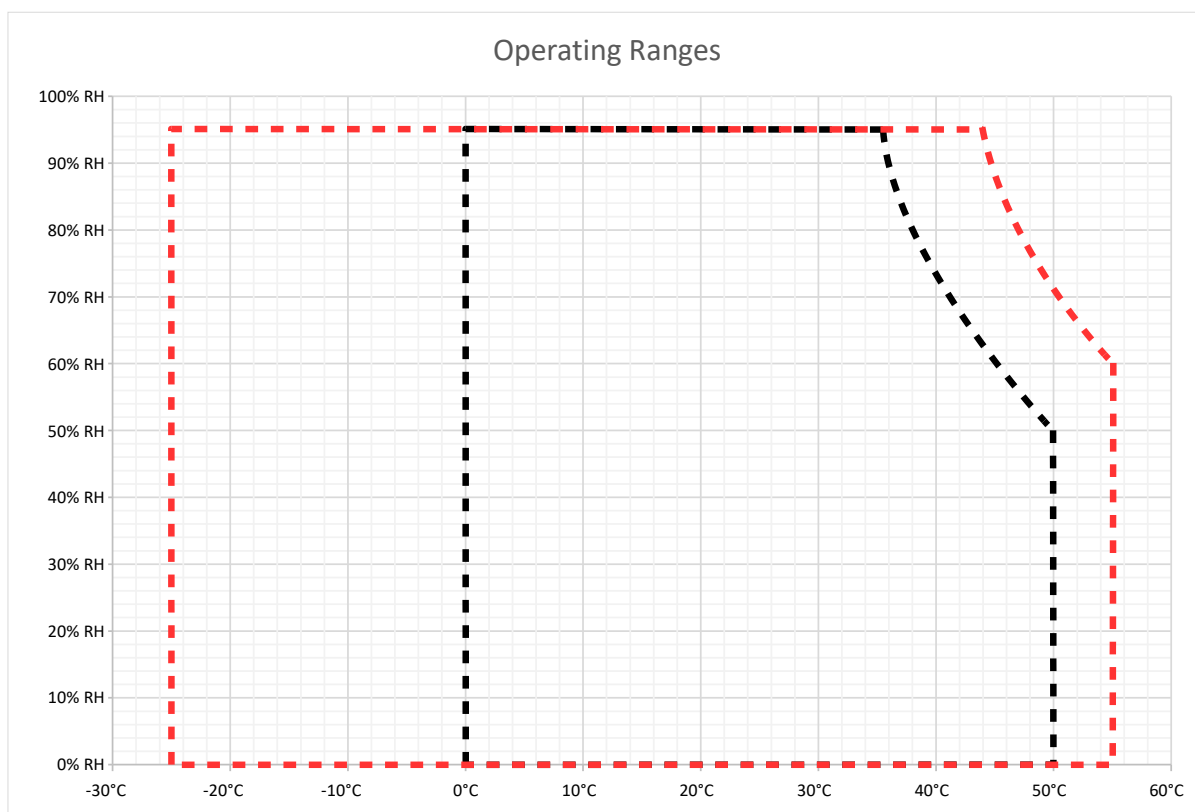
This approximation ignores the effects of pressure. Generally, increasing the pressure increases the dew point, and reducing the pressure lowers dew point.

This formula can be simplified further to the following for RH < 50%.

$$Dew\ Point\ Temperature\ (Tdp) = T - \frac{(100 - RH)}{5}$$

## SENSOR OPERATING RANGE

GSS sensors are available in two temperature range options, 0°C to 50°C and -25°C to 55°C. Both sensor types are designed to operate in non-condensing environments up to 95% relative humidity.



However, using the above formula, at 95% relative humidity, there is only a 1°C difference between the ambient temperature and the dew point temperature.

## EFFECTS OF CONDENSATION

GSS sensors are designed to work in a non-condensing environment at up to 95% RH. The function and performance of the sensor are likely to be affected by operating below the dew point. Whilst short term exposure to pure water is unlikely to affect long term performance, water condensing on the gas measurement cavity surfaces will have a temporary impact on measurement accuracy.

Care must be taken to ensure the surface temperature of the sensor mirror surface does not drop below the dew point. If it does, condensation will form on the surfaces, which will have an impact on measurement accuracy. The condensation will affect the optical surfaces in the sensor long before there is any measurable effect on the electronics. Condensation on the optical surfaces reduces the measured optical signal in the sensor, which is interpreted by the sensor as a sharp rise in CO<sub>2</sub> levels. The effect is large, so sensors will typically report full scale concentrations when condensation is present and may take some time to return to normal after the sensor optical surface rises above the dew-point temperature.

## REDUCING CONDENSATION EFFECTS

Warm moist air or gas hitting the sensor with a temperature below the dew point will cause condensation. Therefore, any strategy to mitigate the effects of condensation must be targeted at ensuring the temperature of the sensor is above the dew point.

There are several strategies that can be employed. It should be noted that solid state NDIR sensors based on LED technology do not consume much power, typically <10mW average so there is very little self-heating of the sensor.

## NAFION® TUBING

Nafion® tubing can remove water vapor from a gas stream and is widely used in applications such as breathalysers and medical devices. Nafion® tubing consists of a hygroscopic membrane that is very efficient at removing water vapour under certain conditions. It only works when the gas analyte is in a flow that can be passed through the tubing but is very effective in these conditions. Typically, the Nafion® tubing is connected to the sample gas, and the other end of the tubing connected to a pump and sensor. The gas is pumped from the sample gas collection point, through the Nafion® tubing into the entry flow port of the GSS sensor where it is analysed. Often this is configured as a bypass gas path external to the main body of the gas analyte.

The efficiency of Nafion® tubing in removing water vapour from the gas analyte is application specific but will depend on the gas flow rate, gas temperature and the relative humidity of the gas.

The osmotic behaviour of Nafion® tubing can be affected by contamination so care should be taken during design to ensure performance is not compromised during its lifetime.

## DESICCANTS

In some applications, it may be possible to use a desiccant close to the sensor to reduce the humidity levels and prevent condensation. Note that silica gel should not be used as this absorbs CO<sub>2</sub> thus corrupting the measurement. Desiccants are generally limited in their application as the desiccant will need to be changed once it becomes saturated or baked to expel moisture.

## PHYSICAL FILTERS

Increasing the physical filters between the sensor and the humid air or gas can also reduce the effect of condensation. It is not possible to selectively physically filter the water vapour from the CO<sub>2</sub> gas as water molecules are smaller than CO<sub>2</sub> molecules. So, whilst physical filters cannot selectively filter humidity, the large surface areas of a membrane filter can provide nucleation sites onto which humidity can preferentially condense. Care must be taken when employing such measures to ensure enough time is taken to allow the CO<sub>2</sub> gas to diffuse through the filter for an effective measurement to take place.

All of the above strategies are focused on reducing the relative humidity of the gas analyte. Alternatively, it is possible to focus on ensuring the sensor is always above the dew point temperature. As a general rule of thumb, raising the surface temperature of the sensor about 3°C or more above the temperature of the gas analyte is enough to avoid condensation.

## HEATING THE SENSOR

The very low power of GSS sensors is often an advantage as they generate very little self-heating and will not increase the local ambient temperature. Under condensing conditions, the user can add local dedicated heating to increase the sensor surface temperatures to minimise condensation conditions.

The simplest and lowest cost strategy is to use a thermo electric device such as a Peltier heater close to the sensor. Employing this technique is simple, low cost but uses additional power. Sensor accuracy degrades as the temperature rises so care must be taken to ensure the ambient temperature of the sensor does not rise to high. The sensor noise increases with temperature and although the effect is not noticeable around normal ambient temperatures, it may become more noticeable as the temperature increases above 40°C.

## **PHYSICAL LOCATION AND ORIENTATION**

If condensation does form on the optical surfaces (or elsewhere in the sensor) the long-term effect can potentially be mitigated by orienting the sensor, so the condensation does not collect in the optics but runs out of the optics. Note this does not prevent condensation, but it does speed up the recovery from condensation, for example after a step change in temperature. It also reduces the long-term degradation due to repeated condensation/evaporation cycles.

For ExplorIR® and SprintIR® family of sensors, the sensor should be positioned so that the white membrane filter or flow port is pointing down. This avoids condensation gathering in the 'bowl' of the optics. For the CozIR® family of sensors, the best orientation is when the sensor filter is facing the horizon.

## **SUMMARY**

Condensation is the inevitable consequence of the surface temperature of the sensor dropping below the dew point in moist air or gas. Condensation will attenuate the signal from the LED and therefore degrade the accuracy of the CO<sub>2</sub> measurement. All the avoidance tactics are focused on ensuring that the gas measurement chamber optical surfaces do not fall in temperature below the dew point. To achieve this, either the relative humidity of the moist air or gas must be reduced, or the surface temperature of the sensor increased.

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# Reducing the Impact of Condensation on CO<sub>2</sub> Sensors

## REVISION HISTORY

DATE	RELEASE	DESCRIPTION OF CHANGES	PAGES
13/05/2020	1.0	First revision	All
04/06/2020	1.1	Re-write	All
21/08/2020	1.2	Updated with new operating condition graph.	P.4